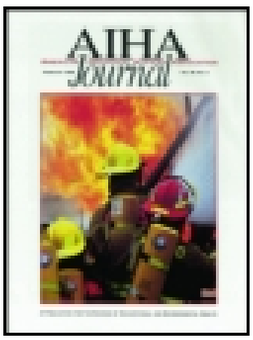

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Ergonomic Considerations in Trucking Delivery Operations: An Evaluation of Hand Trucks and Ramps

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Truck drivers who perform customer deliveries routinely use ramps and two-wheeled hand trucks to unload product from the trailer. During this activity, drivers exert high hand forces when maneuvering the hand truck down the ramp and are exposed to an elevated risk of slips and falls due to increased frictional requirements at the shoe-ramp interface. This study was performed to evaluate the effects of hand truck design, hand truck load, and ramp characteristics on musculoskeletal stresses experienced by drivers when going down ramps. Hand forces and working postures were recorded with motion analysis hardware and software while an experienced driver performed ramp delivery operations using various combinations of hand truck (three types, two braked, one unbraked), product load (three levels, 37, 78, 151 kg), and ramp (four types, three planar surfaces with slopes ranging between 19.1° and 21.6° and one stepped surface with a slope of 19.2°) in a full-factorial design. Hand forces were reduced by more than 60% when using brake-equipped hand trucks. Brakes also reduced the frictional requirements at the shoe-ramp interface. Frictional requirements were reduced with longer ramps and were lowest for the long ramp with the stepped surface. It was concluded that brakes are a very desirable feature for hand trucks used in ramp delivery operations. A strong conclusion regarding ramp design was not reached. Although the stepped-surface ramp required the lowest friction, the noncontinuous design of its walking surface may create a tripping hazard, and additional study is needed.

Keywords: coefficient of friction, ergonomics, hand truck, trucking

Funding for this work was provided by the PFS Division of PepsiCo, Inc., Dallas, TX.
The specific products mentioned in this study were selected as examples of currently available materials handling equipment. Hand trucks, including the types used in this study, can be configured in many different ways to satisfy customer preference. Mention of any specific product and/or product configuration in this paper does not constitute either a recommendation or endorsement of the product.

Falls are the third leading cause of disabling work injuries in the United States, accounting for 17% of lost-time workers' compensation cases across all occupational titles.[1] In the trucking industry, falls are the leading cause of compensable work injuries among drivers, accounting for 22.1% of all claims filed.[2] Truck drivers routinely are exposed to work activities that increase the risk of falls, including ingress to and egress from tractors and trailers; maneuvering two-wheeled hand trucks on ramps, stairs, and loading docks; and carrying large heavy objects that may obstruct the view of the walking surface and/or upset the driver's balance. Environmental factors such as rain, ice, oil, and other contaminants on walking surfaces may further increase the risk of slips and falls due to decreased friction between the shoe and walking surface.[3]

Truck drivers who perform delivery operations routinely use ramps and two-wheeled hand trucks when unloading product from the trailer to the customer. The slope of the ramp depends on its length and the elevation change between the high and low ends. For a typical semitrailer (floor height of approximately 133 cm), slopes of 19° or steeper are observed in situations where the ramp runs between the trailer floor and street level. Slips while standing or walking on inclined surfaces are a particular hazard due to potentially large shear forces at the shoe-ramp interface.[4,5] In the simple, static case of a person standing on a ramp,

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the required coefficient of friction to prevent slipping increases as the tangent of the ramp's slope. For the case of a 20° ramp, the required coefficient of friction to prevent slipping under purely static conditions is 0.36. Dynamic activities during delivery operations such as walking down a ramp while controlling a loaded hand truck may increase the risk of slips and falls. The combined momentum of the mass in the hand truck (loads in excess of 200 kg are not uncommon) and the mass of the driver adds to the shear force at the shoe-ramp interface, increasing the likelihood of a slip. Furthermore, the hand forces required to control and decelerate a moving, loaded hand truck may contribute to loss of balance, challenge the strength capabilities of the driver, and/or increase biomechanical loads on musculoskeletal tissues throughout the body.

An 18-month research project was initiated in January 1996 as a collaborative effort between the University of Michigan's Center for Ergonomics and a food services company that supplies fast food restaurants throughout the United States. The goal of this project was to reduce the rate and severity of work-related injuries in the company's trucking and warehousing operations. The company operated 21 regional distribution centers and a fleet of delivery trucks. Due to close proximity to the university, a distribution center in southeast Michigan was selected to serve as the primary study site. Total employment at this location, including administrative personnel, was approximately 95; the largest job classifications were truck driver (n = 50) and warehouse worker (n = 30). There were small variations in employment levels in all job categories over the course of the study.

Truck drivers were responsible for all aspects of product delivery, including driving and transferring product from the truck to the restaurants. Transfer activities included extensive manual materials handling tasks such as setting up and restowing delivery ramps at each site; selecting product from three storage locations (frozen, refrigerated, and dry) in the trailer; stacking product (typically corrugated boxes weighing up to 22 kg) to a two-wheeled hand truck in the trailer; and maneuvering the hand truck down the delivery ramp and into the restaurant. A typical route involved delivery of roughly 16,000 kg of product distributed over approximately 12 restaurant stops. At a typical stop, 15–17 hand truck loads were transferred from the trailer to the restaurant. Most drivers ran 1-day routes, returning to the distribution center after a driving/delivery schedule with a duration of about 10 hours. A few drivers had multiday routes requiring overnight stops. Drivers worked 4 days per week.

A joint labor-management committee was established at the distribution center with the general charge of reducing work-related injuries and improving ergonomic working conditions in the truck driving and warehouse jobs. Membership included warehouse and transportation managers, the facility maintenance manager, and experienced warehouse workers and truck drivers. University ergonomists participated as facilitators and technical resources. This committee identified ramp delivery tasks as a cause of injury among truck drivers, and requested that the university perform an ergonomic analysis of this operation. This recommendation was subsequently confirmed by a survey of drivers at the Michigan site. Among the 41 drivers participating in the survey, the task of maneuvering unbraked hand trucks down ramps was the most frequently cited cause of physical stress on the job. Eight drivers (19.5% of the sample) considered ramp operations to be the single most strenuous materials handling activity in their jobs.[6]

A comparison of the Michigan site with other work locations revealed that the company used a large variety of hand trucks and ramps in its 21 distribution centers. Based on this information, a study was undertaken to determine best work practices for controlling ergonomic stresses during ramp operations. The goal of this study was to evaluate the effects of hand truck design (braked versus unbraked), hand-truck load (mass of product handled), and ramp characteristics (length and surface configuration) on the stresses experienced by drivers. The results of this study were used to develop recommendations for equipment selection and work practices when using hand trucks on ramps.

TABLE I. Independent Variables in Biomechanical Studies

Loads			
Product	**Mass (kg)**		
Chips (six cases)	37		
Cheese (eight cases)	78		
Frozen meat (eight cases)	151		
Hand Trucks			
Truck Type	**Mass (kg)**		
M-S (unbraked)	14		
M-B (braked)	15		
R-B (braked)	21		
Ramps			
Ramp Type	**Length (cm)**	**Slope (deg)**	**Mass (kg)**
Back ramp 1	410	19.2	49
Back ramp 2	412	19.1	48
Step ramp	410	19.2	44
Side ramp	366	21.6	49

METHODS

Dependent Variables

The following dependent variables were measured or computed:
(1) Hand forces exerted by drivers when maneuvering hand trucks down ramps. This variable was measured directly using electronic load cells mounted to the trucks.
(2) Friction requirements at the shoe-ramp interface, computed from force measurements and load characteristics.
(3) Indices of biomechanical strain (strength requirements relative to population strength capabilities, compression forces acting on the lower back) computed from force and posture measurements using commercially available hardware and software.

Additional details on equipment and measurement procedures are presented below.

Independent Variables

Independent variables were selected to represent the typical range of loads handled by drivers and the types of ramps and hand trucks used across the 21 distribution centers. Table I presents a summary of the independent variables and Figure 1 shows photographs of the tested hand trucks.

Hand truck load was evaluated at three levels, ranging between 37 and 151 kg. The product combinations shown in Table I were typical examples of light, moderate, and heavy hand-truck loads likely to be encountered by a driver on a route. (Note: Although drivers in practice sometimes placed more than 225 kg of product on a hand truck, for safety reasons this extreme load was not tested during the study.)

Two of the three tested hand trucks were equipped with brakes. Truck M-S (manufactured by Magline, Inc., Pinconning,

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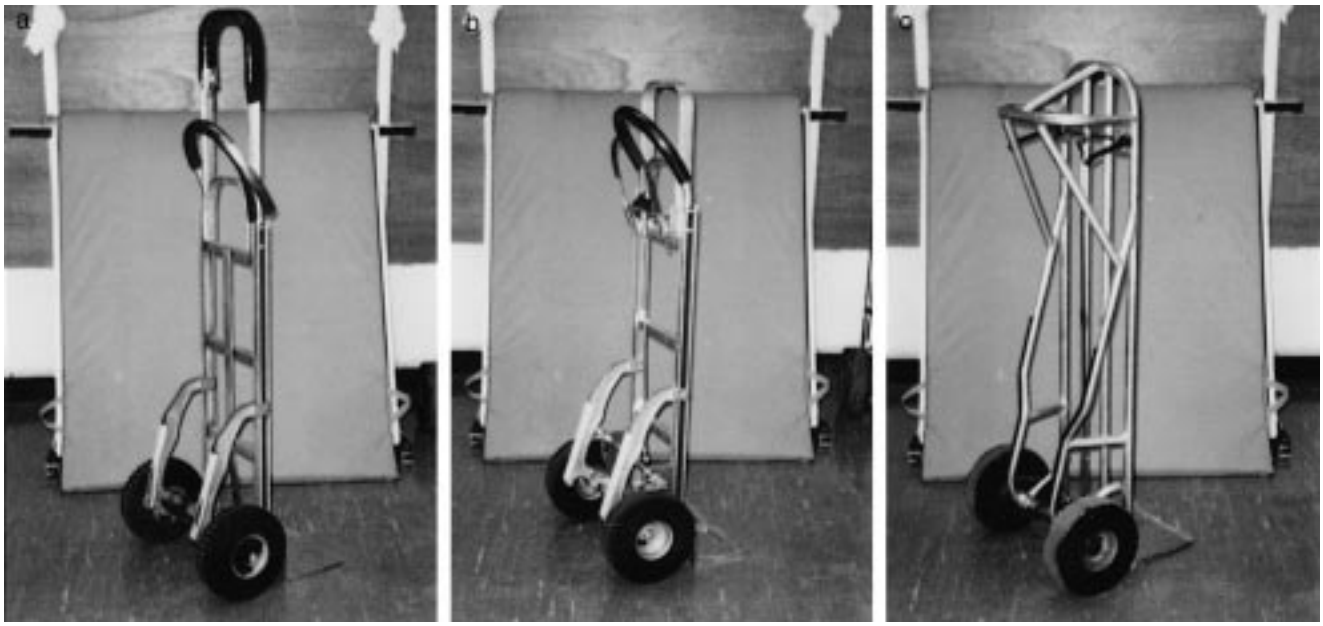

FIGURE 1. Hand-truck configurations tested: (a) unbraked Truck M-S, (b) braked Truck M-B with single-pull handle, and (c) braked Truck R-B with dual brake handles

Mich.) had no brakes. TruckM-B (also manufactured by Magline, Inc.) utilized a center pull ring to activate metal friction plates that rubbed against the tread surface of the hand truck tires. Truck R-B (model # BC10–10-P with Austin handles, produced by Reavis Manufacturing, Kansas City, Mo.) utilized two handle-mounted brake controls to activate an internal hub brake on each wheel.

The first three ramps in Table I were similar in length and mass. (These longer ramps are typically used at the rear door of the trailer and are commonly called "back ramps.") As illustrated in Figure 2, Back Ramps 1 and 2 both featured continuous planar walking surfaces, while the step ramp utilized a series of horizontal stepping surfaces separated by open spaces (similar to an open staircase). The fourth ramp (called a "side ramp" because it typically is used at the side door of the trailer) featured a continuous planar surface and was significantly shorter than the first three. All four ramps featured high-friction (e.g., grates, nubs, etc.) steel walking surfaces to reduce the likelihood of slips and falls.

Confounding Variable—Driver

Because of differences in equipment and work practices at the 21 distribution centers, there was concern that a driver's familiarity with or preference for certain types of equipment might influence the dependent variable. Therefore, two drivers from different centers were selected to serve as subjects.

(1) PT (male, age 43 years, height 186 cm., weight 96 kg., 18 years truck-driving experience). PT was employed at the Michigan distribution center and normally used truck M-S (an unbraked hand truck) with either Back Ramp 1 and the side ramp. (Both ramps were carried on the truck; the driver could choose either depending on the layout of the delivery site.)

(2) CB (male, age 53 years, height 179 cm., weight 83 kg., 25 years truck-driving experience). CB was employed at the Kansas distribution center and normally used truck R-B (a braked hand truck) and the step ramp.

Due to severe time constraints on data collection (scheduling demands on trucks and drivers required that all data be collected in a single experimental session commencing at 10:00 p.m. and ending 9 hours later at 7:00 a.m.), it was not possible to run each driver under a full replication of all combinations of independent variables (three trucks × four ramps × three loads). Therefore, Driver PT was tested with two replications of each condition (72 ramp trips) whereas Driver CB was tested only under the conditions shown in Table II (30 ramp trips). Pilot testing found relatively small subject differences (less than 8%) in the hand forces exerted by the two drivers. As will be shown below in the Results section, no significant driver effect was found the analysis. However, the inability to test Driver CB under all conditions prevented examination of the significance of driver × equipment interactions. Furthermore, the limited set of observations on Driver CB reduced the power of the ability to detect a driver effect. Some of the consequences of these limitations are presented below in the Discussion section.

Equipment and Procedures

The food services company provided a tractor trailer rig and cases of product (see Table I) for the trials. The ramps and hand trucks were either provided by the food services company or by the manufacturer. Hand trucks were modified by the University of Michigan to allow direct measurement of hand forces.

To record the movement dynamics needed as inputs for the biomechanical analyses, body posture was captured using the LiftTrak™ video motion analysis system (Motion Analysis Corp., Santa Rosa, Calif.). A flow chart of the data collection and analysis process in presented in Figure 3. This system required that six retro-reflective markers be attached to the subject at the ankle, knee, hip, shoulder, elbow, and wrist. During data collection, these markers were illuminated with a monochromatic LED light source and the reflections were recorded by a standard VHS video recording system. To capture postures, the video tape was played

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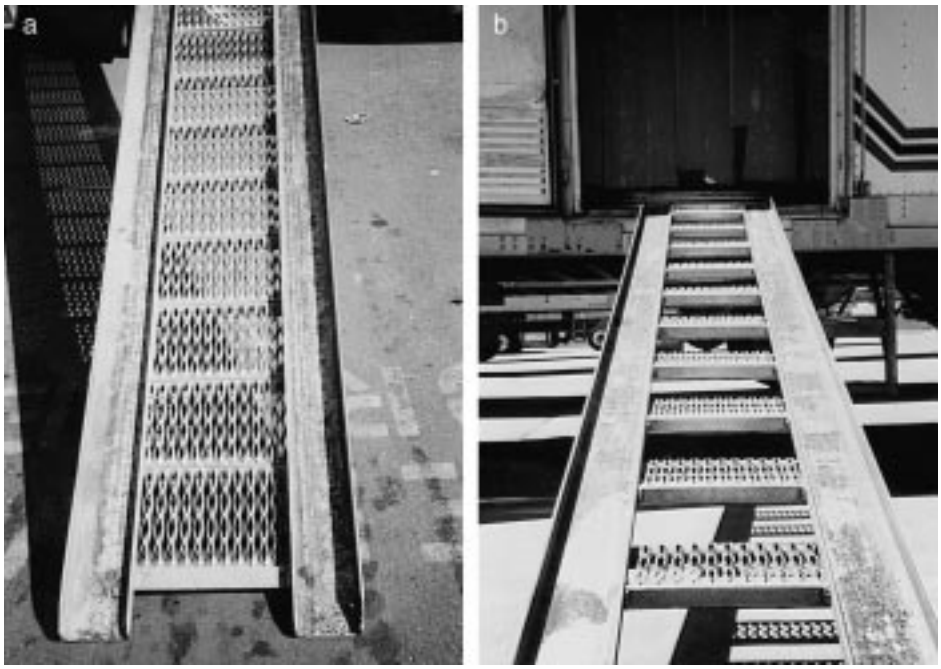

FIGURE 2. Ramp walking surfaces tested: (a) the back ramps and the side ramps featured a continuous planar steeping surface; (b) the step ramp featured a series of horizontal steps similar to an open stair case. High-friction grating was used on all four ramps. Note the smooth-surface wheel tracks found on both ramp types.

and the locations of the markers were extracted by the LiftTrak system. The body link angles were then automatically calculated and entered into University of Michigan Three-Dimensional Static Strength Prediction Program™[7] to compute biomechanical strain.

Hand forces, required for the biomechanical analysis, were measured directly by fitting each hand truck with a strain gage-instrumented handle to record the vertical and horizontal components of the driver's exertion. A custom-designed interface box converted the force data into video targets, which were recorded by the VHS system simultaneously with the posture information described above. The LiftTrak system extracted force and posture data on a common time scale. The vertical and horizontal forces were resolved into a single resultant force and used to compute both average and peak hand forces when the hand truck was maneuvered down the ramp.

Because the posture recording system could be adversely affected by ambient lighting conditions (i.e., point sources that could be mistaken for reflective markers), it was necessary to collect all data at night. Data collection began at approximately 10:30 p.m. on October 10, 1996, and continued until dawn (approximately 6:30 a.m.) on October 11 in a dimly lit campus parking lot. Because many deliveries to restaurants occur at night (routes are usually dispatched shortly after midnight), the data collection session coincided with the drivers' normal schedule, and lighting conditions were similar to those encountered during a predawn delivery.

Figure 4 illustrates the ramp delivery task under both daylight conditions and the nighttime lighting conditions used for data collection. Both images were captured from a VHS video tape. Note that under nighttime conditions (Figure 4b) only the reflective markers are visible. These marker locations were captured during video playback to determine joint centers for the kinematic model used in the biomechanical analysis.

TABLE II. Combinations of Ramps and Hand Trucks Evaluated with Both Drivers during the Biomechanical Study

Ramp Type	Hand Truck Type	Comments
Back ramp 1	M-S (unbraked)	normal setup for PT
Side ramp	M-S (unbraked)	normal setup for PT
Step ramp	M-S (unbraked)	
Step ramp	M-B (braked)	
Step ramp	R-B (braked)	normal setup for CB

Note: Each driver performed two replications with three different loads.

Data Analysis

Data were processed by LiftTrak and University of Michigan strength prediction software. Analysis of variance procedures and SAS software (SAS Institute, Inc., Cary, N.C.) for the Macintosh were used to determine the statistical significance of the independent variables on the outcome measures of interest. Results are summarized and interpreted in the following sections.

RESULTS

Main Effects of Independent and Confounding Variables

Analysis of variance was performed to assess the significance of the three independent variables (hand truck type, ramp type, product load) and the confounding variable (driver) on average and peak hand forces exerted while maneuvering hand trucks down the ramp. Results are presented in Table III for the five combinations

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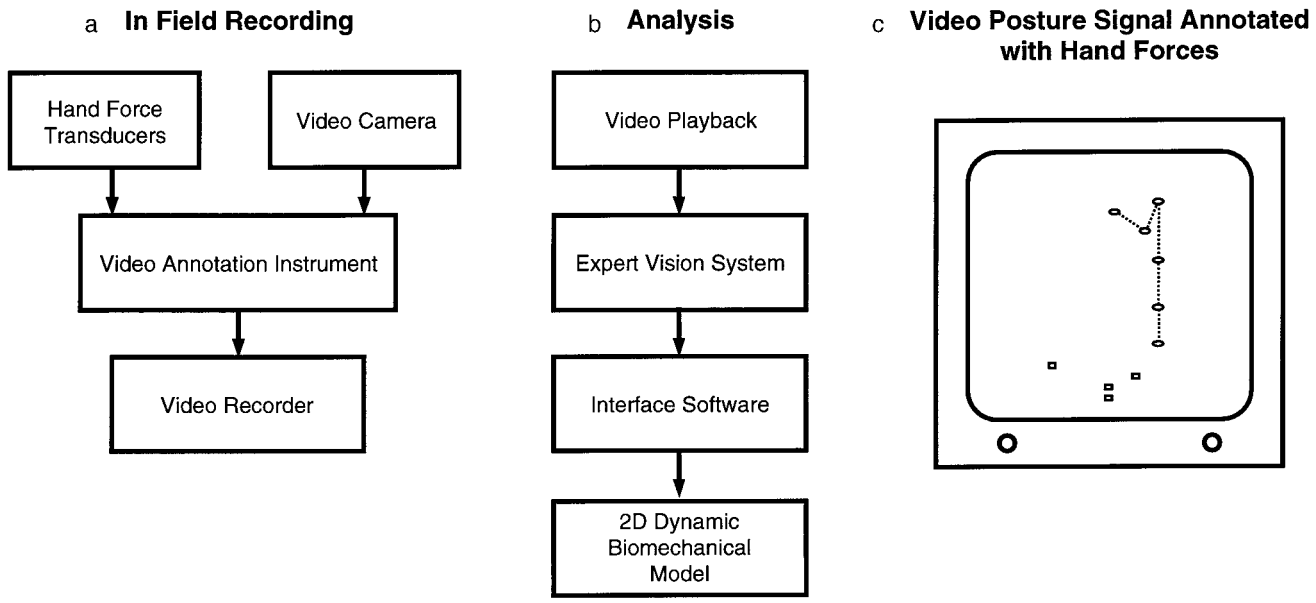

FIGURE 3. Features of data collection system: (a) schematic of data collection hardware, (b) flowchart of data reduction and analysis, (c) sketch showing reflective markers at body joints during playback

of hand truck and ramp used by both drivers. Significant effects, discussed in the following sections, were found for truck type, ramp type, and load. Interactions among the independent variables were not found to be significant. No significant driver effect was found for the subset of experimental conditions tested by both drivers (see Table II). Because no driver effect was found, the analyses presented below are based only on data collected from Driver PT since he participated in the full set of experimental conditions.

Effects of Load on Hand Force

Table IV presents analysis of variance results for average and peak resultant hand forces exerted by Driver PT. The top section of Table IV shows that average and peak hand forces significantly increased with heavier loads in the hand truck. The average hand forces in Table IV were computed over the full duration of time required to maneuver a hand truck down a ramp (typically between 2 and 4 seconds) using a time-weighted procedure. Average hand forces more than doubled when handling the heaviest load (151 kg of frozen meat) compared with handling the lightest load (37 kg of chips). Similar trends were observed in the analysis of peak hand forces. Peak values shown in Table IV were based on the maximum forces exerted during each hand truck trip down the ramp and were approximately 80% greater than the average forces discussed above. Peak forces were usually associated with decelerating the truck at the bottom of the ramp and other situations where the driver needed to exert extra effort to maintain control of the load. The duration of peak exertions was typically very short (fractional seconds).

Effects of Truck Type and Brakes on Hand Force

The center section of Table IV shows that average and peak hand forces decreased substantially ($p<.0001$) when using hand trucks equipped with brakes. Using the unbraked Truck M-S as a baseline for purposes of comparison, substantial reductions in hand forces were obtained with braked trucks. Average hand forces (308 N with the unbraked truck) decreased by 60% with braked Truck M-B and by 64% with braked Truck R-B. Peak hand forces (488 N with unbraked Truck M-S) decreased by 42% with braked Truck M-B and by 60% with braked Truck R-B. A pairwise comparison of the braked Trucks M-B and R-B did not find significant differences for either average or peak forces. These findings demonstrate that equipping hand trucks with brakes substantially decreased hand forces. This issue will be discussed in greater detail in the Discussion section.

Figures 5a and 5b plot regression predictions of average and peak hand forces as a function of product load for the three types of hand trucks. (The regression equations were determined using results from all four ramp types.) Note that the regression lines for the braked Truck R-B were almost flat, indicating that the driver was able to use the braking device to maintain a nearly constant hand force, regardless of the load in the truck for the range of conditions tested in this experiment. Although the braked Truck M-B showed a positive slope with increasing load weight, hand forces were significantly lower than when using the unbraked Truck M-S. For the lowest load tested (37 kg) the average hand force was slightly (but not significantly) lower with the braked Truck M-B than with the braked truck R-B; see Figure 4b. Perhaps this outcome can be attributed to the lower weight of Truck M-B compared with Truck R-B (15 kg versus 21 kg).

Effects of Ramp Type on Hand Force

The bottom section of Table IV shows that average hand forces were significantly related to ramp type. The two flat back ramps were similar in performance, with average hand forces of 155 N and 161 N, respectively. Average hand forces increased to approximately 200 N with the step and side ramps. The increase for the side ramp was expected due to its shorter length and steeper slope. The increase for the step ramp was not expected since its length and slope were quite similar to the long flat ramps (see Table I for dimensions). This unexpected finding may be explained by the fact that Driver PT was unfamiliar with the step ramp and was

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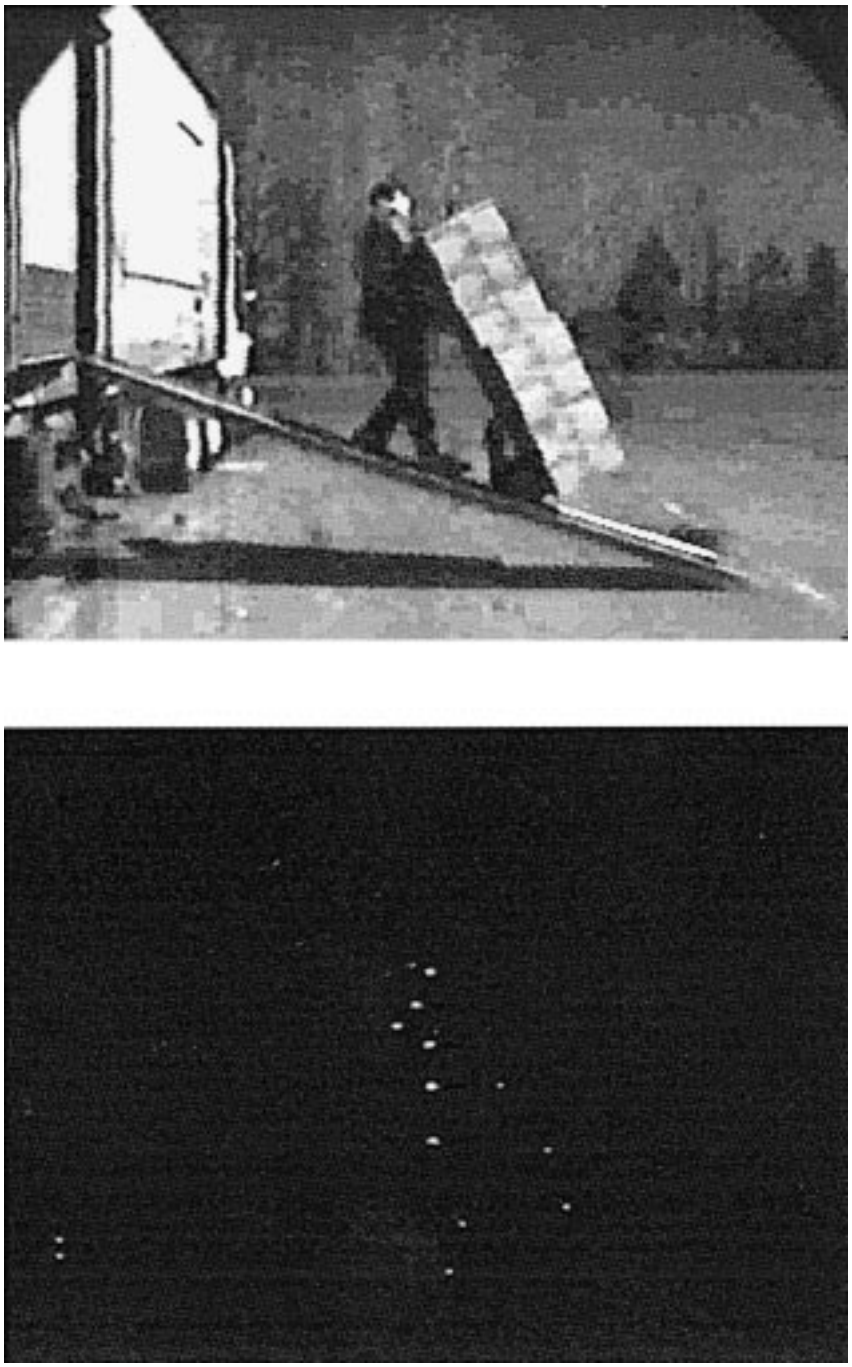

FIGURE 4. Example freeze-frame images captured from video: (a) shows a driver going down a ramp under daylight conditions, (b) shows reflective markers on a driver when going down a ramp under the night conditions used in this study. The brighter reflections in the center of the image are from markers on the driver; the three dim reflections to the right and below the driver are from markers on the truck.

concerned about possibly tripping and falling due to the open spaces between steps. This will be discussed further in the Discussion section.

Peak hand forces followed a trend similar to average hand forces; however, the differences were not found to be statistically significant.

Analysis of Friction Requirements on Ramps

To prevent drivers from slipping while maneuvering hand trucks down ramps it is necessary to select ramp surface treatments and shoe sole materials that will provide sufficient friction for the task being performed. Safety professionals usually recommend a coefficient of friction (COF) of at least 0.5 for walking on level surfaces and a COF of at least 0.7 has been proposed for ramps constructed to comply with the Americans with Disabilities Act.[3,8] (Note: The type of ramp referred to in the American with Disabilities Act is a permanent design feature used for access to and within buildings—this is quite different from the temporary delivery ramps considered in this study.) However, these recommendations are based on the assumption that a person is walking

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TABLE III. Results of Analysis of Variance for Average and Peak Hand Forces for Combinations of Hand Truck and Ramp used by Both Drivers (see Table II).

Variable	Average Force	Peak Force
Product load	.0001	.0001
Hand truck type	.0001	.0001
Ramp type	.0001	.0001
Driver	NS	NS

Note: Entries are significance levels for independent and confounding variables. "NS" indicates that the variable was not found to be significant ($p > .05$).

with no external load imposed on the hands. Ramp delivery operations do not comply with this assumption.

The required COF (RCOF) is a function of several task variables, including ramp slope, driver weight, hand truck load, the presence or absence of brakes, and movement dynamics. To determine RCOFs for the four ramps evaluated in this study, two analyses were performed. The first analysis considered the friction required to restrain an unbraked hand trunk on a ramp (i.e., a theoretically static mechanical system). The second analysis used measured hand forces exerted by Driver PT while maneuvering trucks down the ramps during this study. As will be shown below, RCOFs during ramp delivery can be greater than recommended COFs found in the literature.

Under static conditions, the RCOF for restraining an unbraked hand truck while standing on a sloped ramp surface can be computed as

$$\mathrm{RCOF} = \frac{\sin\theta \times (W + T + L)}{\cos\theta \times W} \quad (1)$$

where: θ is the angle (slope) of the ramp,
W is the weight of the driver,
T is the weight of the hand truck, and
L is the weight of the load in the hand truck.

TABLE IV. Analysis of Variance Results—Main Effects of Product Load, Hand Truck Design, and Ramp on Average and Peak Hand Forces Exerted by Driver PT

Product Load in Hand Truck	Average Hand Force (N)	Peak Hand Force (N)
Chips (37 kg.)	117.2	212.5
Cheese (78 kg.)	172.4	302.0
Frozen meat (151 kg.)	252.6	452.6
Significance of main effect	.0001	.0001
Hand Truck Type	**Average Hand Force (N)**	**Peak Hand Force (N**
M-S (unbraked)	308.3	488.7
M-B (braked)	122.1	281.1
R-B (braked)	111.8	196.9
Significance of main effect	.0001	.0001
Ramps	**Average Hand Force (N)**	**Peak Hand Force (N)**
Back ramp 1	155.5	292.7
Back ramp 2	161.2	293.1
Step ramp	209.8	339.8
Side ramp	196.4	363.0
Significance of main effect	.01	NS

Note: Table entries are grand means for average and peak forces for each level of the independent variables. Interactions were not significant ($p > .05$).

In this example the shear force acting at the driver's feet is expressed in the numerator and is proportional to the sine of the ramp's slope and the total combined weight of the driver, hand truck, and load. Assuming that the hand truck is equipped with frictionless unbraked wheels, there is no friction force acting at the wheels to prevent sliding. Available friction is limited by the normal force acting at the interface of the ramp and the driver's shoes, expressed in the denominator. Equation 1 was used to compute RCOFs when using unbraked Truck M-S on the three continuous

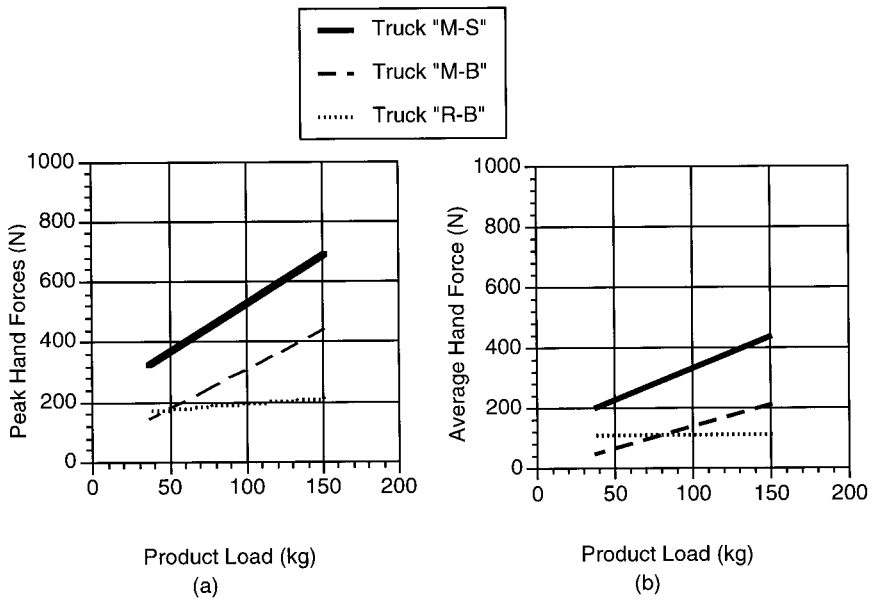

FIGURE 5. Regression plots of resultant hand force versus product load for three types of hand truck. Peak hand force is shown in graph (a), average hand force in graph (b).

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TABLE V. RCOFs for Four Tested Ramps

Ramp Type	Static Analysis			Dynamic Analysis (Driver PT)			
				M-S (unbraked)		M-B (braked)	
	Avg. Female 62.0 kg.	Avg. Male 785 kg	Driver PT 95.5 kg.	avg.	peak	avg.	peak
	RCOF	RCOF	RCOF	RCOF	RCOF	RCOF	RCOF
Back ramp 1 (19.2°)							
Light (37 kg.)	0.63	0.57	0.53	0.53	0.62	0.38	0.50
Moderate (78 kg.)	0.86	0.76	0.68	0.68	0.87	0.42	0.57
Heavy (151 kg.)	1.27	1.08	0.95	0.75	0.98	0.54	0.90
Back ramp 2 (19.1°)							
Light (37 kg.)	0.63	0.57	0.53	0.53	0.68	0.38	0.51
Moderate (78 kg.)	0.86	0.75	0.68	0.67	0.86	0.43	0.54
Heavy (151 kg.)	1.27	1.07	0.94	0.80	1.02	0.62	0.89
Step ramp (19.2°)							
Light (37 kg.)	0.27	0.21	0.18	0.23	0.33	0.04	0.16
Moderate (78 kg.)	0.49	0.39	0.32	0.38	0.55	0.11	0.22
Heavy (151 kg.)	0.88	0.69	0.57	0.50	0.70	0 23	0.40
Side ramp (21.6°)							
Light (37 kg.)	0.72	0.65	0.61	0.60	0.74	0.51	0.63
Moderate (78 kg.)	0.98	0.86	0.78	0.75	1.01	0.58	0.77
Heavy (151 kg.)	1.45	1.23	1.08	0.93	1.37	0.64	0.92

Notes: Static analysis based on forces required to restrain unbraked truck on sloped ramp. Dynamic analysis based on forces measured during experimental trials.

planar ramps (Back Ramps 1 and 2, side ramp). Because body weight is an important determinant of RCOF, results are presented in Table V for three conditions: (1) an average U.S. adult female (62.0 kg), (2) an average U.S. adult male (78.5 kg), and (3) Driver PT (95.5 kg).

Equation 1 cannot be used to estimate RCOFs for the step ramp. The step ramp has two surfaces: continuous sloped rails for the hand truck wheels, and horizontal steps for the driver. This allows the driver to stand on a level surface (slope = 0°); therefore, there is no contribution of body weight to the shear force (sin0°=0). Furthermore, all of the body weight is available as a normal force (cos 0°=1), so Equation 1 reduces to:

$$\text{RCOF} = \frac{\sin\theta \times (T + L)}{W} \qquad (2)$$

RCOFs for the step ramp are also presented in Table V.

To estimate "actual" RCOFs for the conditions tested in this experiment, measured hand forces from the instrumented handles and postures from the LiftTrak motion analysis system were used to compute average and peak shear forces at the feet for Driver PT for each trip down the ramp. This shear force was used as the numerator in Equations 1 and 2, while the normal force (i.e., the denominator) was determined using Driver PT's body weight. Average and peak RCOFs for Trucks M-S and M-B are presented on the right side of Table V.

Table V shows that RCOFs frequently exceed the recommended 0.5 level under both theoretical static assumptions and actual measurements when using an unbraked hand truck on all four tested ramps. By providing brakes the average RCOF drops below 0.5 for the light and moderate loads on all of the long ramps and slightly exceeds 0.5 on the shorter side ramp. For the heaviest load, only the step ramp has an RCOF below 0.5. In addition to demonstrating the effectiveness of brakes, Table V also shows the advantages of long ramps and heavier body weight in reducing required friction.

It is possible to obtain COFs greater than 0.5 by using the grated/abrasive metal walking surfaces used on all four study ramps and by selecting soft shoe sole materials that will conform to the grates.[3] However, available friction can be reduced by contamination (e.g, ice, water, oil, or grease) or erosion of either the shoe sole or ramp walking surface. When selecting ramp surfaces and shoe sole materials it is important to perform the necessary testing to determine how much friction is available under anticipated conditions of contamination and wear. It is also important to maintain surfaces and soles to assure the friction level required for the task does not decrease over time to unsafe levels.

Biomechanical Analyses of Strength Requirements to Control a Hand Truck on a Ramp

An analysis of truck handling was performed using hand force measurements from the instrumented load cells and posture data from the LiftTrak motion analysis system as inputs to the University of Michigan's static strength prediction software. The purpose of this analysis was to determine how strength, body balance, and/or back compression forces can be limiting factors in the amount of weight that can be safely handled in a truck when going down a ramp.

For this task, strength (rather than body balance or back compression) was found to be the limiting factor. For an average-sized male (50th percentile stature and weight), the strength software predicted that approximately 75% of the male population has the strength capability to perform this task when the resultant hand force is 445 N. Referring back to Figure 3a for the unbraked truck, an average resultant hand force of 445 N occurred when handling the maximum load tested in this study (151 kg).

Although the National Institute for Occupational Safety and Health (NIOSH) has not issued specific guidelines for pulling tasks (such as restraining a hand truck on a ramp), the agency has issued recommendations for the strength requirements of lifting

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tasks.[9] For lifting tasks, NIOSH recommends that interventions (e.g., equipment changes or task redesign) be implemented in situations where less than 99% of the male population has the strength capability to perform the task. If the NIOSH recommendations were followed here, average hand forces could be reduced by either (1) reducing the load in the hand truck, or (2) equipping the truck with brakes. (Note: Because the duration of peak loads was so short in this experiment, it is difficult to interpret the results presented in Figure 5b with respect to the NIOSH guidelines.)

DISCUSSION

Hand Trucks and Brakes

Due to the high cost of data collection, this experiment was limited in scope. The results are based largely on observations obtained from a single subject, an experienced delivery driver. In spite of these limitations, the findings present a compelling argument supporting the use of brakes on two-wheeled hand trucks. Average hand forces decreased between 60 and 64% when using brakes, and peak hand forces decreased between 42 and 60%. These results were greatly influenced by the behavior of the driver. By controlling the amount of pressure applied to the brake handle, he was able to maintain a comfortable level of hand truck speed and restraining force. Reducing the pressure on the brake handle would have resulted in faster speed and higher restraining force. (Note: restraining force is defined as the force exerted on the truck to resist its tendency to roll down the ramp). Increasing the pressure on the handle would have resulted in a slower speed and decreased restraining force. Theoretically, brakes could be used to reduce the speed of the hand truck to zero. (The limiting factors here would be the grip strength of the driver and the efficiency of the braking system.) In this situation restraining forces would be nil.

Both drivers reported that the primary advantage of the braked trucks was the increased capability to control their speed while descending the ramp, particularly when handling the heavier loads. Speed control may be a factor in preventing certain types of accidents. In a related study performed at the southeast Michigan food services company, the authors investigated all work-related accidents and injuries experienced by the drivers (n = 50) during a 12-month period: June 1996 through May 1997.[10] None of the hand trucks were equipped with brakes during this period. A total of 14 injuries not related to driving occurred during this time. Of these injuries four (28.6%) resulted from falls caused by losing control of a loaded hand truck on a ramp. Two of the truck/ramp accidents were initiated by a slip (insufficient friction between the ramp and the shoe). The other two were initiated by unexpected movement of the ramp attributed to faulty setup or equipment failure. In these four incidents braked hand trucks may not have eliminated the triggering event. However, the increased control provided by brakes may have allowed the drivers to maintain body balance and prevent a fall. Additional study is needed to evaluate the efficacy of braked hand trucks in preventing these types of accidents and injuries. (Note: Among the 14 injuries cited above, there was 1 additional related case. In this accident a driver lost control and fell while maneuvering a hand truck down a small staircase at one of the delivery sites. Although this study did not consider staircases, it is plausible that brakes would provide many of the same benefits observed with ramps.)

Although brake design features were not considered in this study, driver focus groups at three distribution centers (Michigan, California, and Virginia) stated a preference for hand trucks with dual brake handles, one for the left hand and one for the right hand. Drivers also expressed a preference for internal hub brakes over external metal friction brakes that rubbed against the tread surface of the hand truck wheels. They were concerned that the efficiency of external brakes would be severely compromised by contaminants such as snow on parking lots and fats/oils on restaurant floors.

Ramps

Using the criterion of required friction, it was found that long ramps performed better than short ramps, and the step ramp had the lowest friction requirement of all ramps tested. Using the criterion of hand force, the two flat back ramps resulted in the lowest hand forces exerted by drivers. Although the Step Ramp was expected to have hand force requirements similar to those of the back ramp, this was not the case. Average hand forces exerted on the step ramp were significantly higher than on the back ramps. This finding may have been influenced by the selection of the primary subject for this study, Driver PT. As reported earlier, Driver PT was employed at a site that utilized only flat back and side ramps. During the testing he expressed strong dislike for the step ramp and was quite concerned about tripping or otherwise entangling his feet in the open space between risers. Because of this concern he may have exercised extra caution by exerting more force than necessary while using the step ramp. Driver CB exerted lower hand forces on the step ramp than Driver PT; however, the difference was not found to be statistically significant. Driver CB worked at a distribution center that regularly used step ramps and preferred this design over flat ramps.

Given this result, a quick (and nonscientific) survey was performed using the driver focus groups from the Michigan, California, and Virginia distribution centers to learn more about driver preferences. Strong acceptance of the step ramp was found at sites where this was the only long ramp available. However, drivers expressed safety concerns about and dislike of the step ramp at sites where only flat ramps were used. In this limited study familiarity with a ramp appeared to have a strong influence on driver preferences and concerns. Further research is needed to determine whether there are any biomechanical advantages (e.g., reduced hand force requirements) with the step ramp. In addition, accident data should be studied to see whether ramp type is a factor in falls and other incidents where the driver loses control of a hand truck.

The focus group meetings revealed that drivers were more concerned about issues of ramp handling (ease of movement and setup, ease of storage and retrieval) than about ramp slope. They also mentioned that long ramps cannot be used in all delivery situations; at restaurants with small parking lots, the shorter side ramp is the only ramp that can fit into the available space. It is important to note that equipping hand trucks with brakes can substantially ameliorate the disadvantages of the smaller ramp. Brakes allow the driver to reduce hand forces and control the speed of descent to comfortable levels.

Limitations of this Study

This study was limited in scope, both in terms of the number of drivers tested and the types of delivery situations evaluated.

Due to time and budget limitations, the authors were able to study only two experienced truck drivers, and only one of these drivers participated in the full set of experimental treatments. Although it was not possible to show a significant driver effect when

both subjects were exposed to comparable treatments, the small number of observations in each treatment condition did not provide a high level of statistical power. Additional studies are needed to determine whether driver characteristics such as anthropometry and/or experience in using particular types of hand truck and ramp influence either (1) hand forces required to restrain the hand truck, or (2) required COFs at the ramp-shoe interface. As discussed above, drivers who participated in focus groups expressed strong opinions regarding ramp preferences. Additional biomechanical studies using a larger subject pool of drivers (selected based on experience with specific ramp designs) would enhance understanding of the interactions among driver and equipment characteristics.

This study looked at only one type of delivery task, maneuvering a loaded hand truck down a ramp. Although this is the most common task for drivers who perform food service deliveries, the authors did not consider other hand truck/ramp tasks frequently performed by truck drivers, such as stowage and retrieval of the hand truck or pushing/pulling a loaded hand truck up a ramp (a common task when loading furniture and appliances into a moving van). In up-ramp tasks variables such as hand truck weight may become very important, both in terms of biomechanical stressors and driver acceptance. Additional research that considers ramp design, load weight, truck weight, and the presence/absence of brakes during up-ramp activities is needed to develop the information needed to make appropriate decisions regarding the design and selection of delivery equipment.

This study did not compare the efficiency of various brake designs. Although there was a driver preference for hub-type brakes, the experiment was not structured to evaluate objectively the relative merits and weaknesses of different hand truck braking systems. This is an important issue for persons designing and selecting hand trucks. Additional study is needed, including an evaluation of how environmental contaminants affect the efficiency of differing braking systems.

CONCLUSIONS AND RECOMMENDATIONS

This study presents compelling biomechanical evidence supporting the use of brakes on hand trucks when descending ramps. Prospective scientifically sound studies should be performed to ascertain driver acceptance of brake-equipped trucks and the efficacy of brakes in reducing slip and fall accidents on ramps.

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